Project Name: Scintillator Based Muon System R&D 2004-2007

Classification (accelerator/detector:subsystem) Detector: Muon

Institution(s) and personnel

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Introduction

We propose a three year research program to design and test a prototype muon detector for the linear collider detector. The identification and precise measurement of muons is critical to the physics program of the linear collider. The muons produced from decays of W and Z bosons provide key signatures for the Higgs and possible new particles. Muons may also be produced directly from decays of new particles.

The linear collider detector design includes a muon system that will identify muons, as distinct from hadrons, primarily by their penetration through the iron flux return. The muon system should operate over the widest possible momentum range with high efficiency for muons and low contamination from pions. Because the proposed calorimeters are thin in terms of interaction lengths, hadronic showers will leak into the muon steel. With an adequately designed and proven muon system, it may be possible to measure the leakage and hence improve the energy resolution of hadronic jets. The muon system must maintain stable operation with high reliability since the detectors are largely inaccessible. These are challenging requirements for operation over a span of perhaps 20 years.

A promising design for the muon system is suggested by the successful operation of scintillator and iron calorimeters used in neutrino experiments, such as CDHS, to measure the energy of jets. For example, with 10 cm of Fe between counters, hadronic resolutions of ~0.8/sqrt(E) are typically achieved. A scintillator strip calorimeter based on MINOS style detectors may provide the resolution required for a useful measurement of shower leakage.

For the muon system we propose for the linear collider, the general layout of the barrel muon detectors consists of planes of scintillator strips inserted in gaps between 10 cm thick Fe plates that make up octagonal barrels concentric with the e^+e^- beamline. The scintillator strips, ~5 cm wide and 1 cm thick, contain one or more ~1 mm diameter wavelength shifting (WLS) fibers. Light produced by a charged particle is transported via clear fibers to multi-anode photomultipliers located outside the Fe yoke where it is converted to an electronic signal. There are 14 planes of scintillator with alternating strips oriented at $\pm 45^o$ with respect to a projection of the beam line onto the planes.

We propose to optimize the design of a scintillator-based muon system with a coordinated program of simulation studies and performance measurements of prototype detectors. The simulation studies will include development of software that is integrated into the world-wide LC framework. The software will support different geometry descriptions, parametric variation of geometries and will have a user friendly interface. We will develop techniques to produce the components of a prototype system: iron absorber plates and mechanical support, extruded scintillator strips embedded with wavelength shifting optical fibers, splicing and routing of fibers and their interface to multi-anode photomultiplier tubes and readout electronics. In the first year, several prototype planes and readout will be produced. In the second year, the prototype system (including absorber) will be tested with cosmic rays. In the final year, a system of 8 planes and absorber will be operated in a test beam. Because the muon system is the largest one in the LC detector, it is very important that a realizable design, verified by prototyping, is established early, so that a well-working detector is delivered on time and within budget.

Progress report for FY2003

Summary progress reports from each institution are given below. For each activity, a web address is given where a more detailed report is available. The work at Fermilab was funded as part of the Fermilab budget. LCRD grants were awarded to UC Davis and Wayne State in July. UCLC planning grants were awarded to NIU and Notre Dame in August. UT Austin provided consulting help and loaned us two MINOS prototype MAPMT's with bases.

Software Development

<u>Contributions to the global software effort</u> (Arthur Maciel - NIU)

The NIU group has joined a worldwide effort to develop a universal simulation software framework. The main goal is the specification of detector geometry by software that will “plug in” to the simulation engine. This approach will minimize overlapping efforts, enable direct performance comparisons, encourage sharing of detector representations and allow swapping of sub-detectors through standardized simulation tools, objects, and formats. The early development of the framework has been associated with tracker and calorimeter modules. Because there was no detailed simulation of the U.S. proposed muon system, the NIU group has proposed to the NSF (UCLC) the development of an LCD μSim-compatible muon system representation.

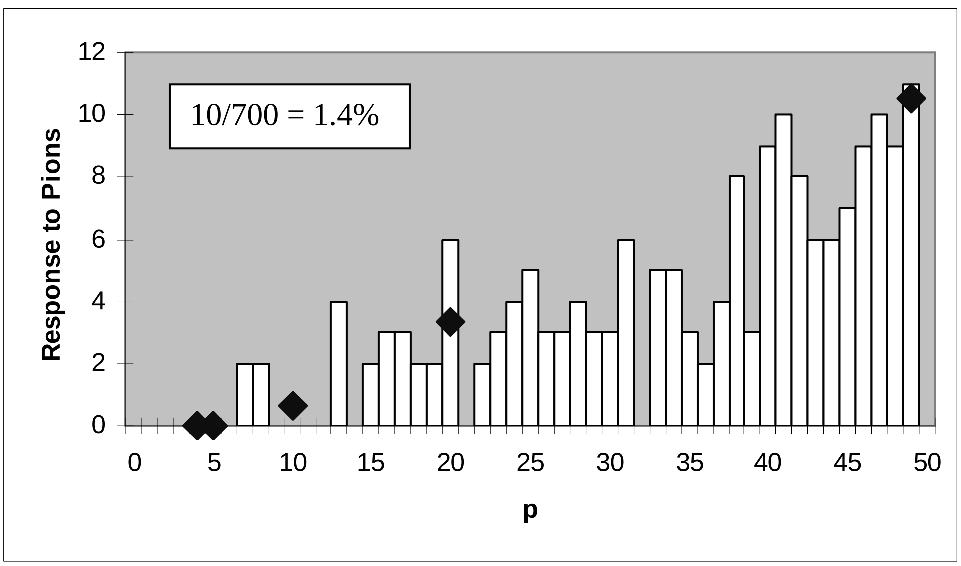
The first steps towards “μSim” are the prototype development by the NIU group that allows planar detector geometries, as distinguished from the existing cylindrical geometry. The software consists of a stand-alone C++ package, with the option to couple to ROOT, in which the representation of a single track is available as a (θ,φ) coordinate pair or a (u,v) pair. This will allow us to study MAPMT channel multiplexing schemes, dependence of muon tracking on scintillator strip layout, widths and stereo angles, ambiguity resolving schemes, parameter optimization, etc.

Further discussion of the NIU prototype software can be found at: http://www-d0.fnal.gov/~maciel/LCD/awg_lcdmu.html.

Contributions to the analysis software effort (Caroline Milstene – Fermilab/NIU)

There has been significant progress in the analysis of Monte Carlo generated events with regard to three topics: muon detector tracking and identification algorithms, tracking efficiency, and hadron punch-through probability. The analysis software development has been done using the SLAC software package: Java Analysis Studio (JAS) and an initial muon tracking Java package developed by Rich Markelov. The Silicon Detector (SD) events that have been analyzed were GEANT3 output samples of single muons and pions. The momenta chosen for each of the 5000 event singles samples were fixed at 2, 3, 4, 5, 10, 20 and 50 GeV/c.

The muon identification algorithm looks for single hits in the muon detectors that are located between 2" thick "cylindrical" Fe solenoid flux return plates. Charged tracks that have been generated upstream of the muon detectors are projected into the muon system and a (θ,φ) match is required for the muon candidate track that is consistent with multiple scattering and energy loss. A plot of efficiency vs. muon momentum shows the efficiency reaches 95% at 4 GeV/c and that it is 99% at 10 GeV/c. The low-momentum efficiency has been increased by including dE/dx in the (θ,φ) matching. This work is an extension of earlier studies carried out by Marcello Piccolo.



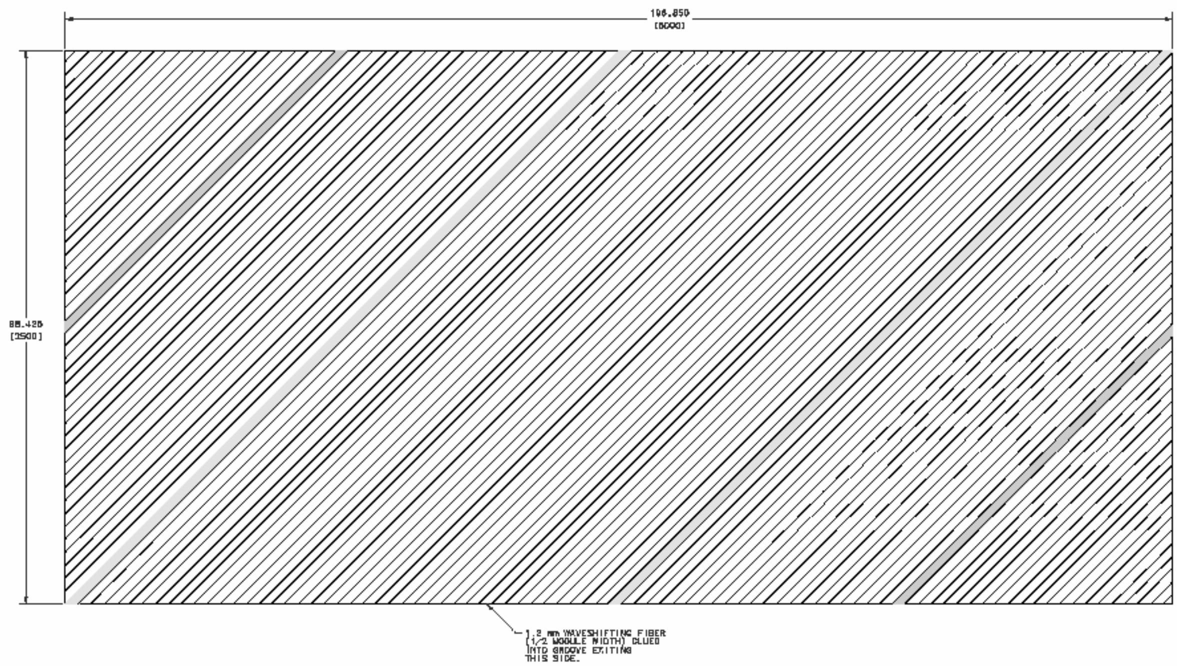
In similar fashion, punch-through has been studied for pions with the same momenta as given above. The analysis results of M. Piccolo are also shown (solid histogram), adjusted for the differences between the TESLA and SD detectors. The punch-through probability is given by dividing by 700, the relative normalization constant per momentum bin for the two analyses. Additional studies are in progress to see if inclusion of hadronic and electromagnetic calorimeter information in the analysis can reduce punch-through.

Present studies are focused on b-pair production where there is at least one muon in the final state. The object is to understand punch-through and identification efficiencies in the midst of jet backgrounds. Further info is available at: http://homefnal.gov/~caroline.

Hardware

Scintillator/Module Design (A. Bross/G. Fisk/K. Krempetz/A. Para – Fermilab)

Work has progressed on the design of 2.5 m by 5.0 m strip scintillator planes. There are the equivalent of 86 strips, with dimensions 4.1 cm wide by 1 cm thick by 3.5 m long, laid adjacent to each other as shown below. The strip scintillator is of the MINOS type (same specification). Requisitions for POPOP, scintillator and fiber (both wavelength shifting and clear) to build seven planes have been submitted. The order for 1.2 mm diameter fiber with 4.5 km of WLS type and 3 km of clear was placed with Kuraray on September 30, 2003. The cost of these orders is approximately: $27.4K for fiber, $4.6K for POPOP and $7.1K for scintillator bars.



Fiber R&D (Mitch Wayne – Notre Dame Univ.)

A first pass design of fiber routes has been made. A drawing for the fiber routes that take into account the splices and bends in he fibers has been made. Splicing of WLS and clear fibers has been done, but the light transmission has not yet been measured. Drafting prints of the various drawings are available at: http://www-d0.fnal.gov/~maciel/LCD/awg_lcdmu.html.

MAPMT Testing and Calibration (Alfredo Gutierrez, Engineer; Rajesh Medipalli, Graduate Student; Paul Karchin – Wayne State Univ.)

The WSU group learned to operate a Hamamatsu PMT with 16 anodes mounted in an assembly used by the MINOS experiment that provides HV biasing and anode routing to mass termination cables. A 16-hole aluminum block was fabricated to route fibers onto the pmt photocathode face. Digital oscilloscope waveforms were recorded of the pmt response to a pulsed, red light emitting diode coupled via a clear optical fiber to the pmt cathode. The charge response of a LeCroy QVT multichannel analyzer was calibrated using a pulse generator and digital oscilloscope, in preparation for absolute charge measurements of pmt pulses. Work on recording anode charge spectra using the LED source is in progress. More details can be found at http://hep6.physics.wayne.edu/~karchin/lcrd.

Readout R&D (Britt Holbrook, Engineer; Juan Lizarazo, Graduate Student; Mani Tripathi – Univ. of California at Davis)

The UCD group has designed and fabricated a printed circuit board, which houses a 16-channel MAPMT. A dynode biasing network and 16 channels of preamplification are provided on-board. The preamplifiers are "in-line" circuits, i.e., the same co-axial cable is used to power the circuit and to carry away the output signal. This feature will lower the burden on the cabling in any future design. The preamplifier rise-time has been measured to be less than 1 ns and hence, we hope to be able to measure the time of arrival (TOA) of single photoelectrons with a 0.5 ns precision. The signals from the preamplifiers are fed into discriminators, followed by TDCs, both of which are CAMAC units borrowed from PREP at Fermilab. The TDCs are read out using the front-panel ECL bus and fed into an FPGA that also provides trigger and control features. Finally, the data from the FPGA are readout into a Linux computer via the parallel port. For reports in greater detail, see http://ucdcms.ucdavis.edu/electronics/ .

Work to be done and deliverables by Institutes

Institute/ Year	Work	Deliverables
FNAL		
FY04	Establish mechanical infrastructure for module production; begin mechanical and electronics infrastructure for test stand; begin procurement of front-end electronics.	several scintillator modules, initial results on module properties
FY05	Procure fiber; complete electronics infrastructure; continue procurement of front-end electronics; begin construction and stacking of iron absorber; begin preparation of mechanical and electronics infrastructure for test beam.	extensive measurements of module properties, infrastructure ready for cosmic ray measurements, report on performance of pmt readout with preamp boards
FY06	Produce full set of modules with extruded scintillator and embedded fibers; complete procurement of front-end electronics; complete setup of iron absorbers; complete test beam instrumentation.	full set of modules and absorbers, infrastructure ready for beam tests, report on results of cosmic ray tests
NIU		
FY04	Develop C++/GEANT4 description of muon system in context of general LC detector framwork; develop muon tracking algorithm; help commission scintillator extrusion facilty at FNAL; design test stand, develop fiber embedding method.	GEANT4 description of preliminary muon detector and demonstration of muon tracking for simulated events, comparative study of extruded and conventional strips
FY05	Optimize detector parameters from simulation; couple muon detector with tracker and calorimeter; measure light yield and time resolution versus position in strip and parameters of the strip and fiber properties.	simulation results for muon efficiency and fake rates for different muon detector designs including integration with tracker and calorimeter, performsnce measurements for strips of various lengths, widths and fiber placements
FY06	Complete optimization of parameters from simulation; write user friendly interface with documentation; produce a significant number of scintillator modules.	completed muon simulation package integrated into LC detector software framework, report on scintillator mass production techniques, quality control and costs
UCD		
FY04	Design/fabricate a preamplifier board for M64 pmt's; provide TDC readout and control using an FPGA.	4 prototype preamp boards, FPGA readout system and a document with test results
FY05	Design/fabricate a board housing 16 dual channel, 1 GHZ flash ADC's and an FPGA controller.	4 prototype FADC boards and a document with instructions and test results
FY06	Produce balance of readout electronics (with help from Fermilab). Install system at Fermilab.	balance of 1024 channels of preamps and ADC boards installed at Fermilab
UND		
FY04	Devise fiber routing scheme; develop fiber splicing method; procure WLS fibers.	description of routing scheme and spicing method, specification of WLS fibers
FY05	Measure optical properties of WLS and clear fibers; design light guide manifolds.	report on fiber measurement system and results, manifold engineering design
FY06	Produce manifolds for 8 planes - install and test.	completed optical distribution system
WSU		
FY04	Procure 4 pmt's and bases - test and calibrate. Install pmt's with scintillator planes at FNAL.	description of calibration procedure and results., records of pulse height spectra with scintillator
FY05	Develop LED calibration system - test at WSU and FNAL. Procure & calibrate 4 pmt's; install at FNAL.	description of calibration system and performance, response for noise and cosmic rays
FY06	Install calibration system at FNAL test beam. Procure & calibrate final 4 pmts's; install at FNAL.	report on performance of calibration and signal response with test beam data

Three Year Budget

Below we include tables of the proposed budgets for the institutions involved thus far in the LCD Muon R&D effort for the years FY04-FY06. Although Fermilab is not requesting UCLC or LCRD funds from the NSF or DOE, the Fermilab LCD Muon R&D budget is given for reference.

DOE University Budget	***FY2004***		***FY2005***		***FY2006***		***Total***	
Salaries and Wages:	***UCD***	***WSU***	***UCD***	***WSU***	***UCD***	***WSU***	***UCD***	***WSU***
Research Engineer		4,004		4,084		4,166		12,254
Graduate Students	13,428	10,449	15,409	17,847	15,717	18,204	44,554	46,499
Undergraduate Students	3,800		4,000		4,200		12,000	
Total Salaries and Wages	17,228	14,453	19,409	21,931	19,917	22,370	56,554	58,753
Fringe Benefits	517	3,363	527	5,091	538	5,193	1,582	13,647
Equipment	9,000	8,000	8,000	8,000	8,000	8,000	25,000	24,000
Travel	3,000	3,250	3,100	3,250	3,200	3,250	9,300	9,750
Materials and Supplies	2,000	2,000	2,000	2,000	2,000	2,000	6,000	6,000
Tuition & Fees	2,330	2,938	4,753	6,111	4,848	6,356	11,931	15,406
Total Direct Costs	34,075	31,066	37,789	40,272	38,503	40,813	110,367	112,150
Indirect Costs	5,914	5,233	6,509	6,802	6,695	6,879	19,118	18,914
Total Direct and Indirect Costs	39,989	36,299	44,298	47,074	45,198	47,691	129,485	131,064

NSF University Budget	***FY2004***		***FY2005***		***FY2006***		***Total***	
Salaries and Wages:	***NIU***	***UND***	***NIU***	***UND***	***NIU***	***UND***	***NIU***	***UND***
Engineer		7,000		8,000		10,000		25,000
Graduate Students	4,635	3,000	4,774	7,000	4,917	8,000	14,326	18,000
Undergraduate Students	3,000		3,000	2,000	3,000	2,000	9,000	4,000
Total Salaries and Wages	7,635	10,000	7,774	17,000	7,917	20,000	23,326	47,000
Fringe Benefits		1,400		1,600		2,000		5,000
Equipment		9,000		9,000		5,000		23,000
Travel	3,000		3,000		3,000		9,000	
Materials and Supplies	5,300		5,400		5,402		16,102	
Subcontract		20,048		20,349		20,532		60,929
Total Direct Costs	15,935	40,448	16,174	47,949	16,319	47,532	48,428	135,929
Indirect Costs	4,113	15,252	4,175	11,423	4,213	10,670	12,501	37,345
Total Direct and Indirect Costs	20,048	55,700	20,349	59,372	20,532	58,202	60,929	173,274

Fermilab LC Muon System R&D Budget	***FY20004***	***FY2005***	***FY2006***
Module Production, Mechanical: parts, fixtures, etc.	17,800	15,000	43,800
Module Electronics: HV, cables, connectors, FE board production	16,500	20,500	20,000
Test Stand Fabrication, including 40T Fe	3,500	13,000	15,000
Test Equipment	8,500	6,000	6,000
Test Beam		15,000	13,000
Labor			
1 FTE Engineer - Mechanical/Electrical	-	-	-
2 Technicians	-	-	-
2 Coop Students	50,000	50,000	50,000
Total	96,300	119,500	147,800